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aSB952
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methyl bromide alternatives

Vol. 2, No. 3 July 1996

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1997 DEC 24 A 11: 09

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Loss of Methyl Bromide: The USDA Forest Service Perspective

Research conducted by USDA's Forest Service, combined with the efforts of cooperators and the insight of nursery managers, could help develop integrated pest management programs that will be needed when methyl bromide is no longer available.

The impending loss of this chemical and the major concerns expressed by various commodity groups, including ornamental and forest nurseries, have underscored the heavy reliance on methyl bromide to provide broad-spectrum control for pest problems.

"The potential loss of methyl bromide has emphasized the need for a better understanding of the pest problems that affect forest tree nursery production in the United States and for the development of alternative strategies to prevent and control these problems," says Jerry Sesco, the Forest Service (FS) deputy chief for research.

Many nursery managers presently rely on routine fumigation with methyl bromide because of its broad-spectrum ability to control diseases, nematodes, insects, and weeds that can affect seedling production and quality, according to Sesco. A basic lack of understanding of how pest problems develop, uncertainty about the potential impact of certain pests on seedling production, and an inability to prevent and control pests through alternative practices essentially mean that fumigation is currently the nursery manager's best "insurance policy" against potential problems.

"We're aggressively seeking to develop better integrated pest management programs that will provide nursery managers with the necessary information to manage complex pest problems through alternative chemical, cultural, physical, and biological control practices," Sesco reports. "Our goal is to provide nursery managers with the best information possible to manage potential pests."

To accomplish this, the Forest Service is supporting research efforts at its laboratories in Athens, GA, and St. Paul, MN. In addition to the Forest Service's State and Private Forestry and National Forest System, cooperators include USDA's Agricultural Research Service, State natural resources agencies, universities, and commercial and industrial nurseries. Research collaborators are investigating alternative pest management practices and collecting information that will be used in developing integrated pest management (IPM) programs. Research efforts include collecting information on factors that influence pest outbreaks and developing alternative pest management strategies to prevent and control losses.

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

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"Our strategy has been to focus on developing both short- and long-term IPM systems," says Stephen W. Fraedrich. An FS plant pathologist at the Southern Forest Experiment Station in Athens, GA, he and colleague L. David Dwinell are working with plant pathologists Jennifer Juzwik and Cynthia M. Ocamb, who are located at the FS North Central Forest Experiment Station in St. Paul, MN.

"In the short term, it is imperative that IPM systems are developed which will minimize or prevent the disruption to U.S. forest tree nursery operations because of the loss of methyl bromide," Fraedrich says. "Therefore, we're placing greater emphasis on the use and application of other soil fumigants as well as other pesticides for these short-term systems. However, because of increasing public attention to environmental and health issues, there are likely to be increasing challenges to using other chemicals in the future. For the longer term, we're working to develop cultural, physical, and biological pest management strategies as well as a better understanding of precisely when specific chemicals are needed."

In St. Paul, Juzwik and colleagues have refined application methodology of the chemical dazomet, enhancing its efficacy for field soil sterilization and control of root diseases in conifer seedlings.

"Root diseases caused by fungi such as *Cylindrocladium* spp., *Fusarium* spp. and *Pythium* spp. are a major problem facing forest nurseries," explains Juzwik. "In trials in the North Central States we've found dazomet as effective as methyl bromide in controlling root diseases, with no harmful effects on seedling quality." She and colleagues will work with Fraedrich and Dwinell from the Athens lab to refine techniques for use of dazomet in southern nurseries beginning this fall.

Researchers at the St. Paul station have extensively screened potential biological control agents to suppress the pathogenic soilborne fungi.

"Preliminary studies showed that applying selected bacteria, along with ectomycorrhizal fungi, protects containerized seedlings against various *Fusarium* fungi," Juzwik says. "We're also conducting bareroot nursery field trials with these same antagonistic, beneficial microorganisms."

Scientists at the Athens lab are studying seedborne fungi and their possible role in disease development in nurseries. Seed orchard and cone harvesting conditions are being studied because they may influence the establishment of pathogenic fungi with seeds. They're also evaluating the efficacy of a nonpathogenic bacterium, *Burkholderia cepacia*, that is reportedly antagonistic to some plant pathogenic fungi.

At both locations, FS scientists are examining ways to disinfest the surface of seeds with chemicals such as hydrogen peroxide as well as investigating potential biocontrol agents to suppress seedborne pathogens.

Efforts are also under way at both locations to determine the underlying causes of disease development. "Studies done in Georgia show that seedling quality was increased in some nursery beds by fumigation," explains Fraedrich. "But in other beds, we've observed no differences in seedling quality in fumigated and non-fumigated treatments. We want to know why certain fields remain productive without fumigation, while seedling quality is reduced and mortality increased in other nonfumigated fields."

The impact of fungi and nematodes on seedling production is of particular interest, he says.

"In the North Central States, soil-water management is critical in controlling root diseases," reports Juzwik. "Maintaining optimal soil moisture is a key factor in minimizing Fusarium losses in both fumigated and nonfumigated nursery beds."

"We have also examined the effect of bare-fallowing, which can control disease losses in the Pacific Northwest nurseries," she continues. "But we have found that this practice is not effective for the control of root diseases in the North Central States."

Future research efforts by the Forest Service will include assessments of

- soil solarization
- the impact of cover crops and organic amendments on soil-borne pests such as nematodes and pathogenic fungi
- efficacy studies of other possible chemicals
- factors that influence the development of pest problems
- various combinations of chemical, cultural, physical, and biological pest control strategies.

Even if a single chemical alternative is found to replace methyl bromide, a more integrated approach for managing pests over the long term is needed because of increasing environmental and human health concerns about chemical use. Resourceful forest managers working with research orga-

nizations, including FS researcher scientists, could help the industry live without methyl bromide.

A Proposed New Quarantine Treatment for Fruit Flies

ARS entomologist Robert Mangan hopes that a combination of controlled temperature and an altered mix of oxygen, nitrogen, and carbon dioxide can keep shipped citrus free of live Mexican fruit flies, a quarantine pest in California and Texas. Parts of California's San Diego County are currently under quarantine for this fruit fly. Mangan is proposing the new treatment as an alternative to methyl bromide, the chemical fumigant now being used that will be discontinued by 2001.

He is testing the proposed method on grapefruit at the ARS Crop Quality and Fruit Insects Research Unit in Weslaco, TX. His goal is in-transit treatments against the threat the Mexican fruit fly poses for any citrus crop grown in California or Texas. "We are testing lots of combinations of the gases," Mangan says. "Results are not conclusive, but some combinations appear very effective at killing Mexican fruit flies."

Krista Shellie, a plant physiologist at Weslaco, is testing fruit quality for the quarantine treatments program. Grapefruit hold up well for a number of the proposed treatments.

Even if this approach succeeds, it would be only one of many kinds of methyl bromide alternatives that are needed. "We would expect this approach to be applicable as a treatment against Mexican fruit fly in citrus during processing and containerized shipping," Mangan says. The in-transit period for produce being shipped from production areas is typically 1 to 3 weeks. Mangan's approach would include placing recording devices in multi-ton shipping containers to track the actual gas mixture and temperature over time. That way, inspectors at the receiving port can determine the treatment's integrity.

The specific mixtures of oxygen, nitrogen, and carbon dioxide gases are proprietary information of the project's industry partner, TransFRESH Corp., Salinas, CA. ARS has a Cooperative Research and Development Agreement with TransFRESH to test the new method for 3 years. Under this agreement, researchers will look for the perfect in-transit treatment that will protect citrus, mango, avocado, and other fresh fruit from pests such as Mediterranean, Mexican, Caribbean, and other fruit flies.

"Keeping shipped U.S. produce free of pests is essential to maintain and expand markets here and elsewhere, such as in Pacific Rim countries," Mangan says.

Typically, USDA's Animal and Plant Health Inspection Service requires that a method must kill 99.9968 percent of pests before it can be approved as an official quarantine treatment.

Telone C-17: Possible Replacement for Methyl Bromide on Bell Peppers

Experimental research by Southwest Florida Farms, a division of Gargiulo, Inc., Immokalee, FL, shows that Telone C-17 worked as effectively as methyl bromide in fumigating soil to rid it of pests before planting bell peppers.

"There were no obvious differences in control of nematodes or soilborne diseases in plots fumigated with methyl bromide and those treated with the chemical Telone C-17," says Tom Mueller. Director of research and development for Gargiulo, Mueller says that both treatments controlled the weed nutsedge fairly equally. He combined Devrinol herbicide with Telone as an in-bed treatment.

"We planted bell peppers in Immokalee back in January of this year, which is a late planting for this area of Florida," he says. "The late winter was also particularly cold, which delayed crop growth. So, we only harvested the crop twice. First harvest yields were considerably higher from the Telone treatment, but the second-pick yields were higher from the methyl bromide treatment. However, overall yields were slightly higher from the Telone treatment."

Mueller's research was part of a large-scale study initiated and conducted by DowElanco in collaboration with the U.S. Environmental Protection Agency and the State of Florida's Department of Agriculture and Consumer Services and its Department of Environmental Protection.

In December 1995, Mueller and colleagues treated one-half of a 16-acre field with Telone C-17, using conventional farm equipment. They injected the chemical into a preformed, raised bed and immediately covered it with polyethylene plastic mulch. About 22.5 gallons of Telone per acre were applied. Prior to bed formation, they applied Devrinol herbicide at a rate of 3 pounds per acre to control nutsedge.

"Using the same equipment, we applied methyl bromide and chloropicrin (98 %/2%) to the remainder of the field on the same day," says Mueller.

A month later, bell pepper transplants were put in the treated field, and irrigated and fertilized through drip irrigation. Field soil type was a Myakka fine sand, common in southern Florida, a growing area characterized by sandy soils, high rainfall, and a naturally high water table that is considered environmentally sensitive.

"Crop growth on the complete experimental site was normal and vigorous," Mueller reports. "We plan to continue this research in the 1996-97 growing season to get data on side-by-side comparisons of methyl bromide and Telone C-17."

Potential Alternatives to Methyl Bromide for Floricultural Crops

Producers of nursery and ornamental crops have relied on methyl bromide for many years to control weeds and soilborne pathogens in ground beds and mixes of potting media. For some diseases, such as Fusarium wilt of carnation, methyl bromide has been the primary means of control for decades. Development of alternatives for the diverse crops and horticultural practices inherent in the nursery and greenhouse industries is a significant challenge.

James MacDonald, a plant pathologist with the University of California (UC), Davis, and several colleagues have been experimenting with potential alternatives to methyl bromide for Fusarium wilt. This wilt, caused by the fungus *Fusarium oxysporum* f.sp. *dianthl*, is the most devastating disease of carnations. MacDonald's collaborators are Manuel Lagunas-Solar, UC-Davis; Steve Tjosvold, a farm adviser from Salinas, CA; Howard Ohr, UC-Riverside; and Ian Green, Salinas Flower Grower's Co-Op, Salinas.

"We're investigating both chemical and nonchemical alternatives," MacDonald says. One approach of particular interest to MacDonald is soil heating. Known to be an effective, nonchemical means of killing soilborne pests and pathogens, heat "is an approach particularly well suited to ornamental production because of the high value of the growing media and the crops," he says.

MacDonald and colleagues have been experimenting with steam and electronic processes for soil heating. "The nursery industry has a long history of using steam," he says. "It's a technology they're comfortable with."

However, steam doesn't heat ground beds deeply enough to eliminate *Fusarium* from carnation's root zone.

"Some growers buried steam manifolds a foot deep in the soil but still didn't achieve effective control. We experimented with buried manifolds, but found that this method doesn't uniformly heat the soil," MacDonald states.

Another method he is using is called ohmic heating. This involves passing electrical currents between an anode and a cathode in the soil, a process which generates heat by the soil's resistance to the flow of the current. MacDonald and colleagues use rows of steel rods, driven into the ground on either side of an empty bed, as anode and cathode arrays.

According to MacDonald, they have been able to heat the soil and kill Fusarium at a depth of 3 feet by driving these rods that depth into the soil.

In addition to soil heating, they've tested surface applications of methyl bromide (to represent current practice), methyl iodide, and Basamid. "In our experiments, methyl iodide provided better control than methyl bromide," MacDonald says. However, efficacy of all chemicals appeared limited to the upper foot of soil. "Ohmic heating was the only treatment that killed *Fusarium* spores to depths greater than 1 foot."

Some carnation growers are converting their operations to raised beds to escape the fungal spores surviving in the soil. While Fusarium wilt can occur in raised beds, the relatively shallow, small soil volumes are more easily treated by steam. But, MacDonald says that disease outbreaks in steamed beds are not uncommon. The pathogen probably gets reintroduced through workers or airborne spores. "I've recovered the pathogen from particles of dust carried on air currents within the greenhouse," he says.

One concern with steaming potting media or raised beds is that it's difficult to control temperatures with steam, so soils may be overheated, eliminating beneficial organisms as well as pathogens.

"The absence of competing organisms can allow pathogens to readily recolonize soils," notes MacDonald. For this reason, he is collaborating with James Locke, ARS, to evaluate potential biological controls. Locke is with the ARS Floral & Nursery Plants Research Unit in Beltsville, MD. MacDonald plans to incorporate Locke's "biologicals" into raised beds after steaming to try to prevent the fungus from re-establishing.

USDA, the California Cut Flower Commission, and the California Association of Nurserymen are funding this research. MacDonald and colleagues are just entering their second year of field trails and are still analyzing data from the first year of research. Preliminary results show the following:

- Ohmic heating was the only treatment that killed fungal spores to a significant depth in the soil.
- Surface-applied fumigants killed the fungus only in the uppermost parts of the soil.
- Methyl iodide appears more effective in surface applications than methyl bromide does.

In addition to controlling pathogens in ground- and raised-bed cropping systems, MacDonald and Lagunas-Solar are exploring the use of microwaves to pasteurize potting media for greenhouse and nursery use.

Broccoli: A Potential Alternative to Chemical Soil Fumigants

Cauliflower brings growers in coastal California about $168 million each year. On 52,000 acres, these growers raise nearly 80 percent of the cauliflower produced in the United States for both fresh and processing markets.

"But a sudden and widespread increase in Verticillium wilt has taken several fields out of production in the Salinas Valley," says Krishna V. Subbarao, a plant pathologist with the University of California, Davis. "Growers suffer extensive losses on crops harvested between April and October."

Since there is no effective control, Subbarao says that the wilt, caused by the fungus *Verticillium dahliae*, presents a significant threat to other cool-season vegetable crops as well. Verticillium wilt attacks more than 300 kinds of plants. The fungal microsclerotia live in soil or on decaying organic matter in the soil and can survive for up to 15 years.

Subbarao and colleagues have found a way to control the devastating wilt on cauliflower without using chemicals: working chopped-up broccoli into the soil before planting cauliflower.

"Although cauliflower and broccoli are related, broccoli resists the wilt even when it is planted in soil heavily infested with microsclerotia. Even broccoli roots are pathogen free, and since broccoli growers haven't complained about the disease, it evidently isn't a problem," Subbarao says.

He says there is also a compound in broccoli (absent in cauliflower) called glucoraphanin that possesses antimicrobial properties. As broccoli decomposes, it produces volatile chemicals that may have an effect on soilborne pathogens.

"We tested the pathogenicity of *V. dahliae* isolates from several crops," Subbarao says. "Our conclusions show that rotations of cauliflower with any crop other than broccoli, Brussels sprouts, and perhaps lettuce, would likely increase the incidence of wilt."

Salinas Valley growers routinely rotate cauliflower with lettuce, maintaining levels of microsclerotia in the soil. Therefore, rotations with lettuce will not control the fungus on cauliflower or other susceptible crops in the short term, according to Subbarao. He and colleagues tried broccoli to reduce the microsclerotia in soil and wilt on cauliflower. They chose cauliflower as a model system because of its importance to California agriculture and because broccoli is grown extensively in the Salinas Valley. Most of the funds for this research project came from several California cauliflower growers, with some financial support from ARS.

Subbarao conducted his research in experimental and grower fields. His 2-year study demonstrated that broccoli residue reduces the number of microsclerotia in the soil and decreases the incidence of Verticillium wilt, making broccoli an ideal candidate for rotation with cauliflower.

"We applied freshly cut broccoli shoots to experimental plots and immediately worked them into the soil," Subbarao says. "Our results show that less wilt developed on cauliflower in

these plots than in plots fumigated with synthetic chemicals."

Tarping had no effect on controlling the fungus. One of the important findings was that the numbers of microsclerotia declined throughout the season and stayed low the following season. However, in conventionally fumigated plots, the numbers declined initially but increased toward the end of the season. This suggests that while fumigation gives short-term control, the effects of broccoli residue are longer term.

Subbarao isn't sure just how broccoli protects cauliflower from wilt. It could be a chemical or a biological mechanism, or both. Applying fresh-cut broccoli could increase the numbers and types of beneficial soil microorganisms such as actinomycetes, bacteria, and fungi, which would selectively inhibit the activity of the fungus.

"The results so far indicate that it may be a combination of both chemical and biological. Any effect of the chemicals is transient since they are volatile and stay in the soil for only a short time," Subbarao notes.

"In soil amended with broccoli, the number of actinomycetes and bacteria increased 1,000 fold, while the numbers of fungi increased only slightly compared with soil not treated with broccoli residue." These microorganisms may have a direct deleterious effect on the microsclerotia; indirectly, the secondary metabolites produced by these microorganisms may also have an effect.

Subbarao's results indicate that after commercial harvest, growers could plow under broccoli residue to manage Verticillium wilt in subsequent cauliflower and possibly other crops as well. "This would not only reduce the wilt, but would also help the environment by cutting the use of synthetic pesticides," he says. "We think that broccoli could be an economically viable substitute for chemical fumigants. The number of years a crop needs to be rotated with broccoli depends on the magnitude of soil infestation by the pathogen."

Broccoli's applicability to other cropping systems needs to be thoroughly researched, Subbarao says. Although it would probably work as a biocultural control on strawberries and other crops, its success should be demonstrated commercially for these crops before it is recommended.

"We propose that broccoli could be a possible alternative for methyl bromide, the fumigant now used by vegetable and strawberry growers in California," he says. Methyl bromide is scheduled to be banned by the U.S. Environmental Protection Agency by 2001.

Alternatves Being Explored in Germany

In Germany, methyl bromide is used primarily to fumigate structures like flour mills and food factories to control pests in stored products. Some of the 90 tons used annually is to control beetles that destroy altars and other precious wooden artifacts in churches and museums.

Christoph Reichmuth says that Germany has greatly reduced its use of methyl bromide, but is still investigating chemical, nonchemical, and integrated pest management strategies as possible replacements. He is director of the Institute for Stored Product Protection, which is part of the Federal Biological Research Center for Agriculture and Forestry in Berlin and Brunswick.

"However, we are urgently searching for ways to modify and optimize our existing use of methyl bromide," he says. "There is a chance that we can further reduce our dosage and still kill pests in stored goods."

According to Reichmuth, the seals in structures being fumigated are routinely tested to ensure quality prior to methyl bromide treatment, often cutting down on the amount of the chemical needed. Even in a fairly gas-tight building, Reichmuth says, about 50 percent of the methyl bromide used in a treatment can be lost in 2 days.

"In a large-scale experiment, we're using charcoal to adsorb methyl bromide instead of venting the gas into the air at the end of fumigation," he says. "But, we need to consider the large amounts of charcoal that would be needed to significantly decrease gas emissions. To be effective, we would need to cut emissions by 50 percent."

In addition to chemicals, since the early 1920's the Germans have been studying the use of a parasitic wasp, *Trichgramma evanescens,* to control moths that cause problems in flour mills. Two of Reichmuth's colleagues at the Institute, Sabine Prozell and Matthias Schoeller, are using the wasp against the warehouse moth *(Ephestia elutella)*, and the Indian meal moth *(Plodia interpunctella).* In Germany, these insects are severe pests in stored grain and the food processing industry.

"Preliminary results are promising that these wasps will find their place in

controlling pests of stored products," Reichmuth reports. "We hope they may replace some chemical control agents."

He says they have shown that controlled temperatures, heat and cold, are a possible replacement for methyl bromide in smaller flour mills. However, he says they have encountered problems with obtaining even distribution of heated and slightly humidified air. Heat treatments must be repeated more often than methyl bromide treatments throughout the year. Other than with methyl bromide fumigation, complete control of all stages of insects in various crevices in structures and inside machinery is hard to achieve. They've observed insects trying to escape heated machinery during a heat treatment.

Regarding cold, both moderate and deep cold treatments are used in Germany, in the form of liquid nitrogen or air, carbon dioxide, or electrical cooling.

Other chemicals that the Germans are trying as substitutes for methyl bromide include carbonyl sulfide and sulfuryl fluoride, as well as combinations of phosphine and carbon dioxide and carbon dioxide under high pressure.

"We've found that elevated temperatures along with phosphine or mixtures of carbon dioxide or nitrogen with low amounts of oxygen fulfill the requirement of quick disinfestation," Reichmuth says. Like methyl bromide these methods leave little or no residue, but they are more expensive. The original research, he says, was done by ARS scientists.

Although the Germans are investigating natural insecticides as potential alternatives to methyl bromide, there is a problem in Germany as there is in the United States, of registering these extracts since they are mixtures of several chemicals.

"Our postharvest pest control market is rather limited and does not guarantee a quick amortization of the registration cost," Reichmuth says. "Therefore, the registration process is slow."

One of the research areas of the future for German scientists is in early detection and monitoring of insects. Since nearly all pheromones of important pests of stored products are detectable and can be synthesized, these are important aspects of integrated pest management. German scientists plan to combine pheromone traps with insecticides or biocides like viruses, *Bacillus thuringiensis,* or entomophagous fungi.

"The way of the future may mean that we use biotechnology to produce new types of insecticides or insect-resistant products," says Reichmuth. "Our search for a cheap, versatile replacement for methyl bromide is far from over."

Technical Reports

Reducing Citrus Fruit Injury From Combination Treatment of Reduced Methyl Bromide Dose Plus Short Cold Treatment

Laurie G. Houck, Research Plant Pathologist and Joel F. Jenner, Biological Science Technician; Postharvest Quality and Genetics Research Unit, USDA, ARS, Fresno, CA 93727.

Treatments developed as alternatives to methyl bromide (MB) fumigation of postharvest commodities for quarantined insects must address concerns of fresh fruit injury as well as efficacy on target insect(s). Although consumers might tolerate certain minor cosmetic injuries to fruit peel if no other treatments are available, any commodity treatments causing major blemishes and decay will not be tolerated or used in commercial situations even if such treatments are approved by regulatory agencies.

Currently, we are evaluating an APHIS-approved fruit fly quarantine treatment using a combination of a reduced MB fumigation dose followed by a short cold treatment. These treatments use 32 g MB/m^3, less MB than is required when MB is used alone (thereby reducing emissions of MB from postharvest commodity fumigations), combined with short cold treatments, shorter and warmer than when cold treatments are used alone. These short cold treatments used in conjunction with MB are less stringent than the longer or stand-alone cold treatments and reduce the expensive time-consuming cold treatments that delay marketing of citrus and increase fruit senescence and decays.

In several tests completed with lemons and navel oranges, we have found that aeration after fumigation and before initiation of the cold treatment is of prime importance. However, an important, and limiting, requirement of the MB + cold treatment combination is that cold treatment must be initiated within 24 hours after MB fumigation.

Lemons aerated for the full 24 hours did not develop objectionable rind

injury discoloration or pitting symptoms characteristic of MB injury and of cold injury (chilling injury; CI). However, sometimes a noticeable mild peel injury did develop even on lemons aerated the maximum allowed 24 hours. This injury would probably not be a major impediment to marketing lemons. Injury was more severe on navel oranges than on lemons and the navel orange injury might not be accepted by consumers. We have only tested late-season navels, however, and this may not be true for early-season navels. Injury to both lemons and navel oranges increased markedly as aeration time was decreased. Injury that developed on fruit after short aeration times was severe and would not be tolerated.

A full 24-hour aeration would delay marketing of fruit, and the warm fumigation/aeration temperature required (21°C) could sometimes lead to an increase in normal rind senescence or injury and fruit decay in storage/shipping/marketing.

Further tests to evaluate the value of forced shorter aeration times following MB fumigation to rapidly remove MB from the fruit and cartons and lessen fruit rind injury will be investigated.

Possible Soil Fumigant Alternatives for Methyl Bromide in Mulched Tomato Production

J. P. Gilreath and J. P. Jones, University of Florida, Gulf Coast Research & Education Center, Bradenton, FL 34203; J. W. Noling, University of Florida,Citrus Research & Education Center, Lake Alfred, FL 33850; and R. J. McGovern, Southwest Florida Research & Education Center, Immokalee, FL 33934.

Fresh market tomatoes, produced on about 50,000 acres and worth up to $450 million annually, are a major horticultural industry in Florida. Most of the winter tomatoes consumed in the U.S.come from Florida, where they are grown on raised, polyethylene mulched beds. Most plants are staked to improve air movement, which reduces relative humidity and incidence of foliar disease, and to keep the fruit from contacting the soil which limits fruit rot. The mild climate and sandy soils which favor crop production also favor many soil-borne pests of tomatoes and other crops. Thus, soil fumigation is vitally important in producing tomatoes in Florida.

The search for fumigant alternatives to methyl bromide for Florida's tomato production began in 1993. What a handful of Florida scientists started as fragmented research on various aspects of soil fumigation has grown into a well-coordinated research and extension program with participation from the University of Florida, the Florida Tomato Committee, the Florida Fruit and Vegetable Association, and the USDA-ARS. Some funding also has been provided by the U.S. Environmental Protection Agency. Soil fumigant field trials, standardized early on, were conducted in most of Florida's tomato producing areas, as well as on the main campus of the University of Florida. We evaluated various soil fumigants for soil-borne disease, nematode and weed control. It was apparent from early trials that no one fumigant would control all of the soil- borne pests that methyl bromide does or as well as methyl bromide.

Nutsedge, both yellow and purple, was one of the most difficult pests to control for any alternative chemical. Purple was more difficult to control and more prevalent in tomato fields in the southern portion of the state where most tomatoes are grown. This weed is capable of penetrating the polyethylene mulch covering plant beds; since control is difficult once nutsedge emerges, it, therefore, flourishes without competition.

We evaluated older, registered chemical fumigants as well as some experimental products and tested efficacy in areas infested with various important soil-borne pests. These included root knot nematode, Fusarium wilt, Fusarium crown rot, Southern blight, bacterial wilt, and purple and yellow nutsedge. Each product had its limitations, some more limited than others. Telone C-17 provided good control of nematodes and some soil-borne diseases; whereas chloropicrin controlled diseases well, but not nematodes. Vapam and Basamid were quite erratic intheir performance. Enzone, an experimental nematicide, failed to control nematodes and damaged tomato plants in some experiments. Fosthiazate, another experimental nematicide, controlled nematodes erratically and did not control other pests. None of the products controlled nutsedge consistently; in some cases, a few actually increased emergence. It became evident that nutsedge control would have to be addressed separately with herbicide. In evaluating these pesticides, we tried to intergrate them into standard tomato production practices of Florida's raised bed, polyethyelene mulch cultural system. Since this system was designed to use a liquid fumigant which could be delivered to the soil under pressure through chisels, liquid fumigants

appeared to be easier for industry to adopt. Vapam, being a liquid, was applied in this manner initially, but did not perform well. Research was conducted to establish a more successful application method for Florida's light, sandy soils. Soil injection with up to 7 chisels in a 36-inch-wide bed was attempted, along with chemigation through micro-irrigation tubing, and various methods of spray application and incorporation in the bed.

Our best success has been to spray Vapam on the soil surface, incorporating immediately with a Rototiller prior to re-shaping the raised bed and applying polyethylene mulch. But efficacy is still less than acceptable in most cases. Applying Basamid, a very fine, powder-like, granular product, is greatly affected by wind which is typically a problem early in the production season in Florida. Additionally, Basamid efficacy appears to be highly dependent on soil moisture level at application and immediately following. Water restrictions in most of Florida's tomato producing areas eliminate overhead irrigation as an option. Therefore, Telone C-17 and chloropicrin currently are considered the most promising alternatives for use in tomato production.

Overall, we found Telone C-17 to be the most consistent and effective alternative product tested to date; however, nutsedge control requires the use of a herbicide with Telone C-17. Few herbicides are registered for use on tomato; few experimental products show promise for this use. Registered and experimental herbicides have been screened for use on tomato with Telone C-17. Tillam herbicide has been the most promising product and is registered for use on tomato. Currently, field trials are underway on University of Florida research farms and on grower farms to further define the efficacy of combining Telone C-17 with Tillam to control major soil-borne pests of Florida's fresh market tomatoes.

Chloropicrin as a Soil Fumigant

Stephen N. Wilhelm, Niklor Chemical Company, Inc., Chairman, Chloropicrin Manufacturers Task Force, Long Beach, CA 90810-1695.

One soil fumigant being tested as a possible alternative for methyl bromide (MeBr) is already EPA registered, available, and practical to use. That compound is chloropicrin (CCl_3NO_2). For over 75 years it has effectively controlled soil pests and pathogens utilizing proven cultivation methods.

Chloropicrin was first tested as a preplant soil fumigant in 1920. In 1957, fruit and vegetable production took a giant leap forward when a mixture of chloropicrin and methyl bromide demonstrated remarkable synergism. Although straight chloropicrin is still applied today in severe soil-borne disease situations, it is typically formulated with MeBr (20-33% chloropicrin) or with 1,3-dichloropropene (1,3-D).

Chloropicrin (molecular weight 164.4) is a small, single-carbon organic molecule that possesses the properties of rapid diffusion through agricultural soil and selective toxicity to common root destroying fungi. It is a clear, colorless, nonflammable liquid with a moderate vapor pressure (18.3 mmHg at 68°F) and boiling point (234°F). Chloropicrin is unique because it is a strong lacrimator (tear producer); therefore, it warns against potentially harmful exposure.

Chloropicrin is injected as a liquid into the soil approximately 6-10 inches below the surface, 14 days or more before crop planting. It kills target fungi within 48 hours of application. Chloropicrin also controls some root-destroying nematodes, soil insects, and other plant-limiting pests.

The importance of soil fumigation in the control of plant pathogens cannot be overstated. Even in agricultural soil with adequate nutrients, water and oxygen, plant growth and crop yields can decline over time due to increasing levels of pathogenic fungi and other pests. In the 1950s, before soil fumigation with chloropicrin, California strawberry growers resorted to applying 500 pounds/acre or more of nitrogen because of plummeting crop yields. The problem was not lack of soil nutrients—it was lack of healthy roots. Strawberry root diseases were widespread at the time and the partially rotted roots were not capable of absorbing the abundant nitrogen that was available. By making high crop yields predictable and at the same time reducing the use of fertilizers, chloropicrin/MeBr combinations have made it possible to replant the same fruit and vegetable land year after year. Predictable crop yields have allowed breeders to concentrate their efforts on fruit quality, appearance, and shipability.

Environmentally, chloropicrin does not have a significant ozone depletion potential because it undergoes rapid breakdown in sunlight. It is metabolized in soil to carbon dioxide. Under anaerobic/aquatic conditions, chloropicrin is converted to

nitromethane within hours. In a plant metabolism study utilizing soil treated with radiolabelled chloropicrin, no chloropicrin or nitromethane was detected in any plant tissue or harvested produce.

The breakdown products of chloropicrin in soil (carbon dioxide, nitrate, chloride) are basic nutrients not only for the plants but also for the microorganisms that inhabit crop soils. The extra salutary effects over and above what would be anticipated from the control of target fungi alone on infested soils are believed to result from the biological activity of root-friendly microorganisms that recolonize the fumigated soil.

Since chloropicrin is only slightly soluble in water (1.6 g/liter at 77°F) it will not move rapidly in aquatic environments. The half-life of chloropicrin in water exposed to simulated sunlight was 31.1 hours with the final products being carbon dioxide, bicarbonate, chloride, nitrate and nitrite. Chloropicrin does not undergo hydrolysis in the absence of sunlight.

The octanol/water partition coefficient ($\log_{10} K_{ow}$) for chloropicrin is 2.5, indicating that it will not significantly bioaccumulate in animal cells. Chloropicrin did not induce cancer in six long-term animal bioassays performed by inhalation, oral, and gavage dosing. Chronic toxicity was limited to inflammatory and other degenerative changes associated with chronic wound healing at the site of dosing (stomach, mouth, lungs). In some *in vitro* ('test tube') mutagenicity studies, chloropicrin induced both negative and positive responses. In animal teratology studies via inhalation, there were no treatment-related fetal malformations. Reproductive fitness was not adversely affected in a two-generation inhalation rat study.

Like most fumigants, chloropicrin is a Restricted Use Pesticide so its distribution and use are highly controlled. Since it does not have the excellent herbicidal properties of MeBr or the broad nematocidal properties of 1,3-D, chloropicrin's use as an alternative will be in conjunction with 1,3-D and compounds with broader herbicidal properties such as metam sodium, dazomet, and pebulate. In the meantime, existing USEPA registrations that contain higher formulation ratios of chloropicrin to MeBr (i.e., 1:1, 1:1.3) than what is typically applied today (1:2, 1:3) can be used. These formulations will provide excellent soil pathogen and weed control without the need to alter current proven cultivation methods.

Upcoming Meetings on Methyl Bromide

Washington, D.C.—October 21-23, 1996

The International Conference on Ozone Protection Technologies will be held again this year at the Washington Hilton & Towers, 1919 Connecticut Ave., NW, Washington, D.C., October 21-23. Formerly the International CFC and Halon Alternatives Conference, these meetings are sponsored by the Alliance for Responsible Atmospheric Policy, the U.S. Environmental Protection Agency, Environment Canada, and the United Nations Environment Programme.

Although meeting agendas have not been finalized, it is expected that methyl bromide will be discussed each day of the conference.

For information on registration and submission of papers, contact Heather Tardel, P.O. Box 236, 312 W. Patrick St., #2, Frederick, MD 21701; telephone (301) 695-3762, fax (301) 695-0175.

Orlando, Florida—November 4-6, 1996

The third annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction is scheduled for November 4-6, 1996, at the Clarion Plaza Hotel, 9700 International Drive, Orlando, Florida. Again, the sponsors will be the U.S. Department of Agriculture, the Crop Protection Coalition, and the U.S. Environmental Protection Agency.

Objectives of the conference are to:

- Enhance scientific information and data exchange on methyl bromide alternatives research.
- Provide a forum for exchange of interdisciplinary scientific and agricultural information.
- Develop and distribute conference proceedings as a state-of-the-art methyl bromide alternatives source for researchers, users of methyl bromide, legislators, Government policy officials, and the general public.
- Support data gathering on potential alternatives to methyl bromide for future evaluation and prioritization.
- Monitor development of viable alternatives to methyl bromide.
- Evaluate technology transfer processes and incentive programs needed to implemen alternatives.

For additional information, contact Margie Upton, Methyl Bromide Alternatives Outreach, Fresno, California, phone (209) 244-4710, fax, (209) 224-2610.

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